NPS-09-97-006

Naval Postgraduate School
Monterey, California 93943-5138

SUMMARY OF RESEARCH 1996

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Prepared for: Naval Postgraduate School
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REPORT DOCUMENTATION PAGE

Form approved

OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 1997	Summary Report, 1 January 1996 - 31 December 1996

4. TITLE AND SUBTITLE
Summary of Research 1996, Department of Mathematics

5. FUNDING

6. AUTHOR(S)

Faculty of the Department of Mathematics, Naval Postgraduate School

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

NPS-09-97-006

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

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13. ABSTRACT (Maximum 200 words.)

This report contains summaries of research projects in the Department of Mathematics. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, technical reports, and thesis abstract.

14. SUBJECT TERMS

15. NUMBER OF PAGES
44

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

DEPARTMENT OF MATHEMATICS

W. MAX WOODS

CHAIR

THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to increase the combat effectiveness of US and Allied armed forces and enhance the security of the USA through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense-related challenges.

CONTENTS

Preface

Research is an integral part of graduate education. At the Naval Postgraduate School (NPS), the goals of research are to:

- Provide a meaningful, high quality, capstone learning experience for our students.
- Keep faculty on the leading edge of advances in defense-related science, technology, management and policy to ensure that the latest information is incorporated into NPS courses and curricula.
- Apply faculty and student knowledge to enhance DoN/DoD operational effectiveness.

Pursuit of these goals increases the technical and managerial capability of the officer corps to keep pace with an increasingly complex defense posture in today's world.

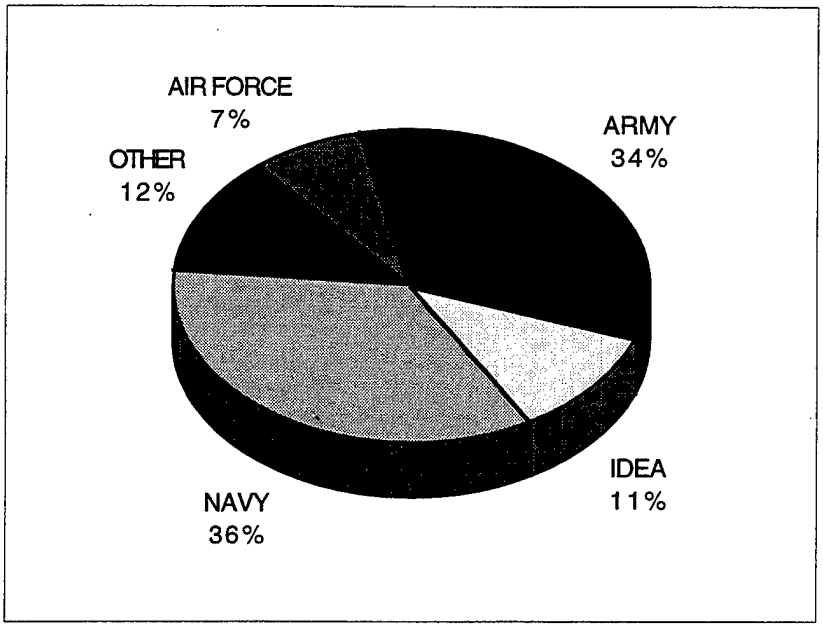
New technologies and policy changes will of course occur, necessitating changes in educational programs and stronger ties between the fleet and the support establishment. NPS must remain poised to face this challenge and to utilize emerging technologies and new policies within its curricula programs. Faculty, therefore, must stay abreast of these developments through a dynamic research program that helps fulfill the School's goals of excellence, uniqueness, and relevance.

The overall research program at NPS has three funded components. The Direct Funded Research and Institute for Joint Warfare Analysis Programs are institutionally funded within the School's operating budget. The Direct Funded Research Program is administered by the Associate Provost and Dean of Research. The Institute for Joint Warfare Analysis Program is administered by the Director of IJWA.

- The Direct Funded Research (DFR) Program provides funding to stimulate innovative research ideas of benefit to the DoN and may be used for cost-sharing with reimbursable research efforts. This funding ensures, in particular, that all Navy-sponsored NPS curricula are equitably supported, that new faculty are provided an opportunity to establish a research program of importance to DoN/DoD and other national security interests, and that faculty and students from across the campus are encouraged to interact with one another.
- The Institute for Joint Warfare Analysis Research Program provides funding to stimulate innovative research ideas with a strong emphasis on joint, interdisciplinary areas. This funding ensures that joint relevance is a consideration of faculty research.
- The Reimbursable Research (RR) Program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policy makers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. This ensures that NPS research remains highly regarded by academic peers and government officials and fosters a closer relationship between NPS and other outside organizations.

The three research programs are complementary and ensure that the overall research program is flexible, responsive, balanced and supportive of the unique needs of the military.

In 1996, the level of the research effort at the Naval Postgraduate School was 141 faculty workyears and exceeded 29 million dollars. Eighty percent of the research was funded by reimbursable sponsors and 20 percent was funded by the Naval Postgraduate School. Sixty-five percent of the work was performed for the Navy and the remainder was sponsored by other agencies, both DoD and non-DoD. A profile of the reimbursable program of the Department of Mathematics is provided in Figure 1:



Size of Program: $269K

Figure 1. Department of Mathematics - Sponsor Profile

Research at NPS is carried out by faculty in the School's eleven Academic Departments, four Interdisciplinary Groups and the School of Aviation Safety. In the pages that follow, research summaries are provided for projects undertaken by faculty in the Department of Mathematics during 1996. An overview and faculty listing are provided as an introduction. A list of publications is also included, if applicable. Abstracts for thesis advised by department faculty in 1996 complete this research summary.

Questions about particular projects may be directed to the Faculty Principal Investigator listed, the Department/ Group Chair, or the Department Associate Chair for Research. Questions may also be directed to the Research Office. General questions about the NPS Research Program should be directed to the Research Office at (408) 656-2098 (voice) or research@nps.navy.mil (e-mail).

August 1997

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DEPARTMENT SUMMARY

The research program of the Department of Mathematics seeks to advance the state of knowledge in the areas important to the Department of the Navy and Department of Defense, such as scientific and parallel computing, fluid flow, orbital mechanics, graph theory, and simulation and modeling.

The specific research areas of our faculty and their students are reported in detail, including sponsors, later in this book. Output in the form of student theses, technical reports, conference presentations, and refereed journal articles is listed here.

Scientific Computation

The area of scientific computation includes both numerical (on serial and parallel computers), and analytical (symbolic) solutions to a variety of problems of interest to the Department of the Navy and Department of Defense. Research has been conducted by Professors Danielson and Neta to compare various analytic, semianalytic, and numerical orbit propagation methods. They also compared various interpolation techniques for Global Positioning System (GPS) satellite orbits requiring high accuracy.

Professors V. Henson and Canright have continued the development of new, more efficient algorithms for solving high speed flows, combining multigrid methods for speed of convergence, multilevel grid-refinement methods for local high accuracy, and parallel implementation for distributed computing on heterogeneous networks for computational speed.

Professor Borges is investigating deflation methods for use in parallel and distributed implementations of divide-and-conquer algorithms he developed with Professor Gragg earlier.

Professors D. and L. Fausett, visiting this year from Florida Institute of Technology, are working on Neural Networks. Applications include pattern classification, color image compression, channel equalization, and combinatorial optimization problems.

On scientific, non-parallel computing, Professor Canright is working on welding problems to determine the scaling and structure of the "cold-corner singularity" in thermocapillary flow in weld pools.

Professors Neta and Giraldo (National Research Council Post-doctorate Associate) have analyzed Eulerian and semi-Lagrangian finite element methods for the solution of advection and advection-diffusion problems with application to air pollution modeling. They also have analyzed the Turkel-Zwas scheme for the solution of the shallow water equations on the sphere (applied to numerical weather prediction) and developed an improvement by using certain staggering suggested by the analysis. This analysis is applicable to any numerical scheme on a sphere.

Professor Borges has continued his research into the tridiagonal QR algorithm for real symmetric matrices.

Professors Frenzen and Scandrett have investigated the behavior of Scholte surface waves propagating along the interface of a por-elastic solid underlying a fluid layer, such as the ocean floor. They have used MAPLE (symbolic manipulator) for some of the work.

Professor Danielson is contributing to the design of ship structures. He has investigated the mechanical behavior of stiffened plates using NASTRAN finite element code.

Professor Franke has continued his work in approximation. He has investigated modeling methods for three dimensional spatial covariance function in order to improve data assimilation techniques.

Professors Fahroo and Kang are working in control theory. Professor Fahroo is continuing the development of the mathematical framework for finding the optimal location of controls for distributed parameter systems such as flexible structures or acoustic fields. She has also cooperated with Professor Kanayama to develop an algorithm for robotic movement. Professor Kang has continued his work in nonlinear control theory and investigated the methodology of stabilization feedback design to minimize the influence of a disturbance on the performance of a nonlinear system. His work is applied to aircraft and spacecraft stabilization.

Simulation And Modeling

Professor Mansager has continued his work on antiarmor weapon system effectiveness. He is also investigating (with Professor Borges) the total force effects of mine countermeasures in amphibious landing. JANUS is extended to model amphibious assaults.

Professors Barr United States Military Academy (USMA) and Neta edited a special issue of the International Journal on Mathematical and Computer Modeling dedicated to combat modeling. This special issue appeared in January 1996.

Discrete Mathematics

Professor Fredricksen has continued his work in computer security concerning the downgrading of security of digital images. The images when displayed on good quality work stations may appear to be unclassified as to content but by embedding classified material into the image it may be possible for a saboteur, for example, to cause this material to be inadvertently released. Interest has been expressed in this project.

Professor Rasmussen has continued his work in graph theory, to produce improve heuristics for solving various NP-complete problems. He has also continued his work on characterization of p-competition graphs.

Professor Owen continues his research into game theory. He is working on multilinear extensions of games and applications.

Professors Jayachandran and Russak have investigated methods for damage assessment for weapon salvos. Improvement to the current empirical rules were proposed.

Professor Woods has developed methods for determining performance expectations of aircraft engines. He has also developed a probabilistic system effectiveness equation to compute the probability that an exocet missile will not hit a DD963 Spruance class destroyer.

DEFLATION METHODS FOR THE REAL SYMMETRIC ARROW MATRIX

C.F. Borges, Associate Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To investigate methods for deflating the real symmetric arrow matrix. This research will include the development of deflation algorithms for use in parallel and distributed implementations of the divide-and-conquer algorithms based on extension, such as the ones described by Gu and Eisenstat, and the one described by Borges and Gragg.

SUMMARY: After looking at this problem, a basic algorithm for deflating the arrow based on Householder reflections was discovered. This algorithm seems more robust than the current known method using rotations. In particular, this method allows the use of block deflations (removing large segments from the matrix) instead of element by element deflation. This method further allows for a single pass deflation of the matrix which is computationally much cheaper than the multiple passes required by the rotation approach. A careful analysis of the off-diagonal fill incurred by the deflation technique was developed with explicit precomputable bounds for its magnitude. This allows one to use the Wielandt-Hoffman theorem to determine the effect that the deflation might have on the location of the eigenvalues, and hence to compute a bound on when to deflate based on the induced error of ignoring the off-diagonal fill.

DoD KEY TECHNOLOGY AREAS: Other

KEYWORDS: Parallel algorithms, eigenproblems

INVESTIGATION OF THE TOTAL FORCE EFFECTS OF MINE COUNTERMEASURES IN AMPHIBIOUS LANDINGS

C.F. Borges, Associate Professor
Department of Mathematics
Sponsor: Office of Naval Research

OBJECTIVE: To investigate the total force effects of various mine countermeasures (MCM) on amphibious landings, particularly the effects in the very-shallow water (VSW) or foam zone, using the JANUS (A) high-resolution combat simulator.

SUMMARY: This research was integrated into a student thesis with LT Tim Weber. A simple scenario was built up for an amphibious assault on a mined beach in JANUS. The results of using different MCM technologies during the assault including bull-breaching, traditional mine countermeasures , and a new swarming technology known as LEMMINGS, which provides for in-stride mine clearing operations, were investigated. One important outcome of this work was that it was shown how JANUS, traditionally a land combat model, can be used to model amphibious assaults. LT Weber completed his thesis on this topic and presented this work at the 64th MORS conference. LT Weber, Bard Mansager, and C.F. Borges have also written a technical report on this work. Various aspects of this work have been briefed to several flag officers and an Assistant Secretary of the Navy

PUBLICATIONS:

Weber, T. Mansager, B. and Borges, C.F. "High Resolution Modeling of Naval Mine Countermeasures," Technical Report NPS-MA-96-004, September 1996.

CONFERENCE PRESENTATIONS:

Weber, T., Borges, C.F., and Mansager, B., "Modeling a Swarming Approach to Mine Countermeasures in an Amphibious Assault," 64th Military Operations Research Society Symposium, Fort Leavenworth, KS, June 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Mine countermeasures, high-resolution combat simulation.

MODELLING AMPHIBIOUS LANDINGS INVOLVING MINE WARFARE

C.F. Borges, Associate Professor
Department of Mathematics
Sponsor: Office of Naval Research

OBJECTIVE: To continue to build upon a model representation of Special Operations units and Mine Warfare components in a traditionally land based combat model. The research will evaluate the ability of the model to capture the salient aspects of these warfare types. These additions, if practical, will make the current JANUS Joint Warfare scenario more robust in its ability to represent operations in a littoral environment. This work will extend our current scenarios of an amphibious landing to include the continuation of operations ashore.

SUMMARY: This research was integrated into the student theses of CPT Bob Lazzell (USA), CPT Ron Middlebrook (USMC), and CPT Kent Wineingar (USA). A fairly complex scenario was built up for an amphibious assault on a mined beach in JANUS. This scenario was based on the KERNEL BLITZ 1995 exercise and attempted to duplicate it in some detail. Actual information was used for staging this exercise to determine troop and equipment placement and routes, etc. Some aspects of this work at the 65th MORS conference. Various aspects of this work will be presented have been briefed to visiting flag officers and others.

THESES DIRECTED:
Lazzell, R.E., "Mathematical Modeling and Analysis of Survivability and Morbidity Rates," Master's Thesis, Naval Postgraduate School, June 1996.

Middlebrook, E.E., "A Combat Simulation Analysis of Autonomous Legged Underwater Vehicles," Master's Thesis, Naval Postgraduate School, June 1996.

Wineinger, R.K., "A Computer Simulation Analysis of Alternatives to the M728 Combat Engineer Vehicle (CEV)," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Mine countermeasures, high-resolution combat simulation.

ANALYSIS OF THERMOCAPILLARY CONVECTION IN WELDING

D.R. Canright, Associate Professor
Department of Mathematics
Sponsor: Office of Naval Research

OBJECTIVE: The goal of this project is to determine the scaling and structure of the "cold-corner singularity" in thermocapillary flow in weld pools. This is a continuing project.

SUMMARY: Recent work in modeling thermocapillary convection in materials processing, for example in the pool of liquid metal formed during welding, shows a region of rapid flow and intense heat transfer, concentrated in the "cold corner" region. A theoretical understanding of this region, currently lacking, is essential for accurate numerical models. The objective of this study is to analyze the coupled thermal and flow fields in this important region. The results should be useful in developing more complete numerical models of the welding process, to understand how to make welds more reliable.

In 1996, the detailed programming for the axisymmetric weld pool problem was nearly completed. This involved discretization of the coupled nonlinear equations and boundary conditions by the Finite-Volume-Element method; in particular, the nonlinear terms and the moving phase-change boundary required special treatment. The coefficients were computed in an innovative way, by using the Maple mathematics software. In implementing the Fast Adaptive Composite grid method, a novel approach was developed for local mesh refinement around the moving solid-liquid boundary. These techniques are on the cutting edge of numerical methods, and are expected to give highly accurate resolution of the fine-scale dynamics in the cold corner region.

PUBLICATION:

Canright, D. and Henson, "A FVE-FAC Approach to Determining Thermocapillary Effects on Weld Pool Shape," Proceedings of the 7th Copper Mountain Conference on Multigrid Methods, NASA ConferencFe Publication 3339, pp. 147-166, 1996.

DoD KEY TECHNOLOGY AREAS: Materials, Processes and Structures

KEYWORDS: Thermocapillary, solidification, welding, crystal growth, Marangoni, convection

LINEAR ELASTIC BEHAVIOR OF ORTHOGONALLY STIFFENED PLATE PANELS

D.A. Danielson, Professor
Department of Mathematics
Sponsor: Naval Surface Warfare Center-Carderock Division

OBJECTIVE: Improve structural design of ships.

SUMMARY: The subject of this work is the mechanical behavior of stiffened plates, basic structural components of ships and submarines. The buckling loads of grillages subjected to axial compression with and without lateral pressure were calculated using a finite element based analysis. Insights were obtained into the ways in which the buckling loads and modes vary with various grillage dimensions, and comparisons were made with actual grillages tested at NSWC.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Materials, Processes and Structures, Surface/Under Surface Vehicles - Ships and Watercraft

KEYWORDS: Plates, stresses, ship structures, buckling

ORBIT PREDICTION USING SEMIANALYTIC SATELLITE THEORY AND PARALLEL COMPUTERS

D.A. Danielson, Professor
B. Neta, Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The development of software was continued for using parallel computers and workstation clusters running PVM (Parallel Virtual Machine software) to predict the paths of Earth orbiting objects. Currently work is on software to prepare input file for Draper semianalytic code for the NAVSPACECOM catalog of orbiting objects.

SUMMARY: Software is being developed to take a catalog entry which is an element set for an object as NAVSPACECOM software requires it and preparing data to use the Draper Semianalytic Satellite Theory (DSST) for propagation. The observations as used for the differential correction process at NAVSPACECOM to format required by DSST are being translated. This will allow one to demonstrate the benefits of the semianalytic theory as compared with the analytic theory.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Artificial satellites, parallel computers, orbit prediction

COMANCHE PROGRAM REVIEW

D.A. Danielson, Professor
Department of Mathematics
E.R. Wood, Professor
Department of Aeronautics and Astronautics
J.H. Gordis, Assistant Professor
Department of Mechanical Engineering
Sponsor: United States Army Comanche Program Office

OBJECTIVE: To study vibration/structural dynamics of the RAH66 Comanche helicopter.

SUMMARY: The activities were continued in support of the Comanche helicopter program. From the correlated finite element model, the modes and frequency responses were obtained. Professor Danielson learned much about Nastran/Pastran at the MSC World Users Conference in Newport Beach, CA. The Comanche prototype in West Palm Beach, FL was visited and the results presented to the American Helicopter Society in St. Louis, MO. Two NPS students were advised who completed experiences tours at Sikorsky and began this Master's thesis work studying the Comanche.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Air Vehicles, Modeling and Simulation, Materials, Processes and Structures

KEYWORDS: Helicopters, dynamics, vibrations

APPLICATIONS OF ARTIFICIAL NEURAL NETWORKS

Laurene V. Fausett, Visiting Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: The goal of this project is to develop a variety of applications of artificial neural networks. These applications serve to illustrate the usefulness of computational techniques in the broad and rapidly evolving field of neural networks.

SUMMARY: During the current year Laurene Fausett and students applied several types of neural networks to problems of pattern classification, color image compression, and channel equalization. Using neural network techniques for parallel solution of a system of linear equations was investigated. A neural network based on the sinc function was also developed.

PUBLICATIONS:

Delgado, H.J. and Fausett, L.V., "Parallel Solution of a Linear System Using an SOR Neural Network," Proceedings of Southcon 96, Orlando, FL, 25-27 June 1996.

Elwasif, W.R. and Fausett, L.V., "Function Approximation Using a Sinc Neural Network," Applications and Science of Artificial Neural Networks II, S.K. Rogers and D.W. Ruck (eds.), SPIE, Volume 2760, pp. 690-701, 1996.

Fausett, L.V., "Boltzmann Machines," in Encyclopedia of Electrical and Electronics Engineering, John "Webster (ed.), John Wiley & Sons, (to appear).

Fausett, L.V., "Similarity Based Learning for Pattern Classification," Applications and Science of Artificial Neural Networks II, S.K. Rogers and D.W. Ruch (eds.), SPIE, Volume 2760, pp. 26-33, 1996.

Fausett, L.V., "Supervised Learning," in Neuroengineering and Neurocontrol: The State of the Art, Nydia Lara (ed.), (to appear).

Lee, J., Beach, C.D., and Fausett, L.V., "Channel Equalization Via Fuzzy ARTMAP," Proceedings of the 7th International Conference on Signal Processing Applications & Technology, Vol. 2, pp. 1397-1401, Miller Freeman, Inc., 1996.

Russell, G. and Fausett, L.V. "Comparison of Function Approximation with Sigmoid and Radial Basis Function Networks," Applications and Science of Artificial Neural Networks II, S.K. Rogers and D.W. Ruck (eds.), SPIE, Volume 2760, pp. 61-72, 1996.

CONFERENCE PRESENTATIONS:

Delgado, H.J. and Fausett, L.V., "Parallel Solution of a Linear System Using an SOR Neural Network," Southcon 96, Orlando, FL., 25-27 June 1996.

Elwasif, W.R. and Fausett, L.V., "Function Approximation Using a Sinc Neural Network," Applications and Science of Artificial Neural Networks, SPIE, Orlando, FL, 9-12 April 1996.

Fausett, L.V., "Similarity Based Learning for Pattern Classification," Applications and Science of Artificial Neural Networks, SPIE, Orlando, FL, 9-12 April 1996.

Russell, G. and Fausett, L.V., "Comparison of Function Approximation with Sigmoid and Radial Basis Function Networks," Applications and Science of Artificial Neural Networks, SPIE, Orlando, FL, 9-12 April 1996.

THESES DIRECTED:

Byung-Taek Min, "Cluster-Mapping Neural Networks for Pattern Classification," Computer Science, Florida Institute of Technology, May 1996.

Jihun Cha, "Color Image Compression Using Clustering," Computer Science, Florida Institute of Technology, May 1996.

DoD KEY TECHNOLOGY AREAS: Computing and Software

KEYWORDS: Artificial neural networks, parallel computing, algorithms

ADAPTIVE HOPFIELD NEURAL NETWORKS

Donald W. Fausett, Visiting Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: The goal of this project was to improve the performance of the Hopfield neural network by using its energy function values to adaptively modify its coefficients. The Hopfield network is notoriously sensitive to its coefficient values, and heretofore there has been no systematic algorithm to determine a good set of values. This deficiency has severely restricted its potential applicability for solving combinatorial optimization problems.

SUMMARY: For the past two years, concluding in the first half of the current year, Donald Fausett and a student investigated methods for determining the coefficients of a Hopfield neural network adaptively as the network evolves based on direct evaluation of the energy function. A systematic way to determine balanced coefficient values was found

and implemented, based on a steepest ascent procedure. An efficient scheme for updating values of the energy function was also devised. The efficacy of this modification was demonstrated in several applications, including the Traveling Salesman Problem, the N-Queens Problem, and the Map Coloring Problem.

PUBLICATIONS:

Park, C.-Y., and Fausett, D.W., "Determination of Adaptively Adjusted Coefficients for Hopfield Neural Networks Utilizing the Energy Function," Applications and Science of Artificial Neural Networks II, S.K. Rogers and D.W. Ruck (eds.) , SPIE, Vol 2760, pp. 36-43, 1996.

Park, C.-Y., and Fausett, D.W., "Energy Function Analysis for Improved Performance of Hopfield-Type Neural Networks," Intelligent Engineering Systems Through Artificial Neural Networks, Vol 5, C.H. Dagli et al. (eds.), ASME Press, pp. 995-1000, 1995.

CONFERENCE PRESENTATIONS:

Park, C.-Y., and Fausett, D.W., "Determination of Adaptively Adjusted Coefficients for Hopfield Neural Networks Utilizing the Energy Function," SPIE 10th Annual International AeroSense Symposium, Orlando, FL, 8-12 April 1996.

Park, C.-Y., and Fausett, D.W., "Energy Function Analysis for Improved Performance of Hopfield-Type Neural Networks," ANNIE '95 Artificial Neural Networks in Engineering Conference, St. Louis, MO, 12-15 November 1995.

THESES DIRECTED:

Chiyeon Park, "Energy Landscape Analysis of the Performance of Hopfield Neural Networks as a Method of Solving Combinatorial Optimization Problems," Ph.D. Dissertation, Florida Institute of Technology, August 1996.

DoD KEY TECHNOLOGY AREAS: Other

KEYWORDS: Hopfield neural network, combinatorial optimization problems

OPTIMAL DAMPING DESIGN FOR FLEXIBLE STRUCTURES

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The goal of this study was to examine different damping designs for achieving exponential stability of flexible structures.

SUMMARY: In this study the question of "optimal" damping design for flexible structures in an abstract setting was addressed. Work includes precise definition and analysis of various design criteria which are of importance in applications. In particular, damping designs were considered to achieve not only exponential stability but moreover obtain better and faster rate of decay for the energy of the system. The results were illustrated in application to a damped wave equation, and performed numerous numerical experiments for different damping designs for this example.

PUBLICATIONS:

Fahroo, F., and Ito, K., "Optimum Damping Design for an Abstract Wave Equation," Kybernetika, Vol. 32, No. 6, pp. 557-574, 1996.

CONFERENCE PRESENTATION:

Fahroo, F., and Ito, K., "Variational Formulation of Optimal Damping Designs," AMS Conference on Control of Distributed Parameter Systems, Mount Holyoke College, MA, June 1996.

DoD KEY TECHNOLOGY AREAS: Materials, Processes and Structures.

KEYWORDS: Distributed parameter systems, damping mechanism, optimization.

EXPONENTIAL STABILITY OF A COUPLED FLUID/STRUCTURE SYSTEM

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The goal of this project is to propose a new acoustic-structure model and prove its exponential stability. In addition, numerical approximation of the coupled system and its convergence and stability properties is studied.

SUMMARY: In this project a fluid-structure model was considered, which consisted of a two dimensional air cavity and a vibrating flexible beam that formed a portion of the boundary of the cavity. A "porous" boundary condition was proposed for the beam equation which allowed the flow of air through the beam.

The focus of the work was on establishing uniform exponential stability for the model, and to achieve this goal the multiplier technique was used, which has already been used successfully in establishing exponential decay rates for wave equations with boundary feedback damping. After proving the desired stability result for the infinite-dimensional model, the effect of choosing different boundary conditions on the stability of the model was explored by performing numerous numerical simulations and different numerical schemes were also investigated that would preserve the exponential stability of the original model under approximation.

PUBLICATIONS:

Fahroo, F., and Wang, C., "A New Model for Acoustic-Structure Interaction and its Exponential Stability," accepted in the Applied Mathematics Quarterly, December 1996.

Fahroo, F., "Exponential Stability of Polynomial Galerkin Methods for an Acoustic-Structure Model," Proceedings of the 4th IEEE Mediterranean Symposium on New Directions in Control and Automation, Crete, Greece, June 1996.

CONFERENCE PRESENTATIONS:

Fahroo, F., "A New Model Of Acoustic-Structure Interaction and its Exponential Stability," MTNS 96 Conference, 24-28 June St. Louis, MO, 1996.

Fahroo, F., "Exponential Stability of Galerkin Methods for an Acoustic-Structure Model," SIAM Annual Conference, Kansas City, KS July 1996.

Fahroo, F., "Numerical Experiments on Approximated Acoustic-Structure Systems," Conference on Computation and Control, Bozeman, MT, August 1996.

DoD KEY TECHNOLOGY AREAS: Other (Active Noise Control)

KEYWORDS: Exponential stability, acoustic structure models, numerical approximations

LINE AND CIRCLE TRACKING FOR NONHOLONOMIC AUTONOMOUS VEHICLES

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The goal of this project is to develop a new algorithm for nonholonomic vehicles for tracking a given line or a circle.

SUMMARY: In this joint research project with Professor Kanayama from the Department of Computer Science at NPS, F. Fahroo investigated the problem of finding an algorithm for the movement of a vehicle under the nonholonomic constraint to track a given directed line without allowing any spinning motion. A new principle was proposed of computing the derivative of path curvature as a linear combination of the current vehicle path curvature, vehicle orientation, and positional difference. We call this function *steering function*. By linearization we found an optimal selection of parameters for critically damped motions and obtained a single parameter, *sigma* (or *smoothness*), for tracking. Numerous simulation results as well as experimental results were obtained on the autonomous robot Yamabico at the Naval Postgraduate School which showed the effectiveness of this method.

PUBLICATIONS:

Fahroo, F., and Kanayama, Y., "A New Line Tracking Method for Nonholonomic Vehicles," submitted to the IEEE Journal of Robotics and Automation, October 1996.

Fahroo, F., and Kanayama, Y., "A Circle Tracking Method for Nonholonomic Vehicles," submitted to the SYROCO 97 Conference on Robot Control, Nantes, France, December 1996.

DoD KEY TECHNOLOGY AREAS: Ground Vehicles, Other (Robotics).

KEYWORDS: Nonholonomic vehicles, path tracking, steering function

COVARIANCE FUNCTIONS FOR 3-DIMENSIONAL DATA ASSIMILATION

Richard Franke, Professor
Department of Mathematics
Sponsor: Naval Research Laboratory

OBJECTIVE: The objective of the proposed work is to investigate methods for more rigorous modeling of the three-dimensional spatial covariance function for the error in numerical weather forecasts, with the goal of improving data assimilation methods. One aim will be to determine properties that will guarantee that the model has the requisite positive definiteness. The computational penalty imposed by non-product forms will be investigated.

SUMMARY: A survey of current methods for generating 3-dimensional covariance functions was conducted. Most of these rely on the assumption of homogeneity and isotropy. One promising method for generating nonisotropic covariance functions is through the use of one-to-one transformations of the data, then the application of a known valid covariance function. By computing the transformation and the approximation of given data simultaneously promising results have been obtained. Work is continuing on these ideas using real data from the FNMOC NOGAPS model. An important by-product of the work will be estimates of the vertical error correlation for radiosonde observations.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Objective analysis, data assimilation, covariance functions, numerical weather prediction

SCHOLTE WAVE PROPAGATION

C. Frenzen, Associate Professor
C. Scandrett, Associate Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this research was to Investigate the behavior of Scholte surface waves propagating along the interface of a poro-elastic solid underlying a fluid layer. Basic properties in the propagation of Scholte surface waves were to be explored to determine when Biot-Stoll theory versus visco-elastic modelling of the ocean bottom is more appropriate. Aspects of surface wave scattering from regions of discontinuous or rapidly changing sediment characteristics was also to be investigated by applying bi-orthogonality relationships for porous, elastic, fluid, or layered media developed by the authors.

SUMMARY: When the ocean bottom is idealized as a fluid layer over a porous half-space, the bi-orthogonality relationship developed by the Principal Investigators is not applicable because of the absence of a full set of propagating normal modes having the proper decay at infinity. This research amended the idealization of the problem to that of a thick poro-elastic substrate over a fluid layer which involves the determination of characteristic propagating mode wavenumbers. Because great numerical precision was required for their determination, the researchers adopted a MAPLE based coding which allows for an arbitrary number of significant digits to be employed. Two large data sets were produced with elastic layers, one hard (basalt), the other soft (shear wave speeds on the order of hundreds of meters per second). The porous layer frequency equation is currently being developed as well as a second MAPLE code which will use wavenumber data to determine Scholte wave scattering from layers of differing material.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Sensors, Other (Environmental Effects)

KEYWORDS: Scholte surface waves, Biot-Stoll theory, visco elastic modelling, MAPLE

ALGEBRAIC MULTIGRID FOR LARGE-SCALE SIMULATIONS ON UNSTRUCTURED GRIDS

Van Emden Henson, Assistant Professor
Department of Mathematics
SPONSOR: Lawrence Livermore National Laboratory

OBJECTIVE: With the ban on nuclear weapons testing, the United States must rely heavily on numerical simulation as a primary means of ensuring the safety and reliability of the nuclear arsenal. Accordingly, the United States has embraced "science-based stockpile stewardship," a program in which traditional test-based methods are supplanted by virtual testing and prototyping. Several applications important to this mission require the numerical solution of elliptic Partial differential equations (PDEs) on extremely large grids whose gridpoints are irregularly spaced-unstructured grids. Algebraic Multigrid (AMG) is a method developed for use with unstructured grids. This project seeks to: 1) determine whether AMG can be used on such problems; 2) to demonstrate the feasibility of its application to the problems in question; 3) to convert existing AMG codes to a modern, structured computer language; and 4) to design an AMG algorithm that can be implemented efficiently on massively parallel processing systems, enabling the use of parallel AMG on real problems. This project has resulted in a production-grade algebraic multigrid code for serial machines, and will develop an AMG code for massively-parallel computers.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Nuclear weapons testing, stockpile stewardship, Algebraic Multigrid (AMG)

MULTIGRID, MULTILEVEL, AND MULTILEVEL PROJECTION METHODS

Van Emden Henson, Assistant Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To formulate theoretical foundations of the multigrid, multilevel, and multilevel projection method, and apply them to several problems, specifically to the image reconstruction problem and to the solution of certain nonlinear Partial Differential Equations (PDEs).

SUMMARY: This work is the unfunded continuation of projects funded in 1990, 1991, and 1992 by the Naval Postgraduate School. Multigrid and multilevel methods are numerical computation methods that take advantage of all of the scales of a problem in order to accelerate the convergence to the solution. Design and implementation of the methods, however, is not simple, and many workers have resisted using them because of their complexity. Recently a new approach called multilevel projection was formulated by Stephen F. McCormick which greatly simplifies the design and implementation of multilevel methods. This project investigates the theoretical foundation and the application of these methods to several types of problems, including solution and grid refinement methods for PDEs, specifically certain semilinear elliptic equations that arise in non-Newtonian fluid flow, and multilevel methods for image reconstruction (the Radon Transform problem).

PUBLICATIONS:

Briggs, W.L. and Henson, V.E., "A Table of Analytical Discrete Fourier Transforms," Applied Numerical Mathematics, Vol. 20, pp. 1-10.

Henson, V.E., Limber, M.A., McCormick, S.F., and Robinson, B.T., "Multilevel Image Reconstruction with Natural Pixels," SIAM Journal Of Scientific Computing, Vol. 17, No. 1, pp. 193-216, 1996.

Henson, V.E., and Shaker, A.W., "Theory and Numerics for a Semilinear Elliptic PDE, with an Application in the Theory of Pseudoplastic Fluids," to appear in Applicable Analysis.

Henson, V.E., and Shaker, A.W., "Multigrid Solution of a Semilinear Elliptic PDE with an Application in the Theory of Pseudoplastic Fluids," to appear in Applicable Analysis.

Canright, D. and Henson, V.E., "An FVE-FAC Approach to Determining Thermocapillary Effects on Weldpool Shape," Refereed by conference organizers, in Proceedings of the 7th Copper Mountain Conference on Multigrid Methods, NASA Conference Publication 3339, pp 147-166, 1996.

CONFERENCE PRESENTATIONS:

Henson, V.E., "Image Reconstruction from Projections using Adjoint Interpolation," Copper Mountain Conference on Iterative Methods, April 1996.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Image reconstruction, multigrid, multilevel projection

PROJECT SUMMARIES

AN INTENSITY DISTRIBUTION FOR CONCURRENT SOFTWARE FAILURES

Toke Jayachandran, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: It is now well known that independently developed multiple versions of software systems do fail dependently, i.e., several different versions of software can fail simultaneously for certain inputs. The assessment of the reliability of such redundant software must take into account this concurrent failure phenomenon. A probability model that incorporates such failures, has been proposed by Tomek et al.; they explicitly derived the probability distribution for n=2 and n=3 software modules and indicated that the derivation for larger n would require an efficient algorithm.

SUMMARY: An algorithm for determining the probability that exactly k out of n software modules will fail has been derived and a MAPLE program to compute the probability distribution has been developed.

PUBLICATIONS:

Toke Jayachandran, "Correlation in Multiversion Software," Naval Postgraduate School Technical Report NPS-MA-96-003, October 1996.

DoD KEY TECHNOLOGY AREAS: Computing and Software

KEYWORDS: Software reliability, redundancy, intensity distribution

NONLINEAR H∞ CONTROL, DISTURBANCE DECOUPLING AND THEIR APPLICATIONS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To study the methodology of feedback design for the purpose of robust stability and minimizing the influence of disturbances on the performance of nonlinear control systems. The theory is believed to be useful to problems such as aircraft control, under water vehicle control, helicopter control, etc. The proposed research problems are solvability of HJI equations, bifurcations of control systems, and applications of control theory to mechanical systems.

SUMMARY: The theory of H∞ control is useful for the purpose of minimizing the influence of disturbance on the performance of a control system. Solving the problem of H∞ control is equivalent to the problem of solving a PDE called HJI equation. The relation between the solvability of HJI equation and the associated Riccati equation is studied. Conditions for the existence of a global solution to HJI equations are found.

A control system has, in general, infinite many equilibrium points. The stability properties at different equilibrium points are not always the same, especially when bifurcation occurs. The equilibrium sets of control systems and their bifurcations are classified based on normal forms and invariants of the system.

In nonlinear systems such as flight or spacecraft control systems, determining the domain of attraction is critical. Some results on the domain of attraction and HJ type of equations are proved. One of the results shows that the domain of attraction can be determined by the solution of a HJ equation in optimal control.

PUBLICATIONS:

Byrnes, C.I., Delli Priscoli, F., Isidori, A., Kang, W., "Structurally Stable Output Regulation of Nonlinear Systems," Automatica, (accepted).

Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems - Part I," SIAM Journal of Control and Optimization, (accepted).

Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems - Part II," SIAM Journal of Control and Optimization, (accepted).

Kang, W., "Bifurcation and Topology of Equilibrium Sets," Proceedings of the IEEE Conference on Decision and Control, 1996.

Kang, W., "Bifurcation and Topology of Equilibrium Sets," Proceedings IEEE Conference on Decision and Control, Kobe, Japan, December 1996.

Kang, Wei, "Extended Controller Form and Invariants of Nonlinear Control Systems With a Single Input," Journal of Mathematical System, Estimation and Control, 6, pp. 27-51 1996.

Kang W. and Huang, J. "Calculation of the Minimal Dimension K^{th}-Order Robust Servo-Regulator," IEEE Transactions Automation and Control, (accepted).

Kang, W. and Huang, J., "Calculation of the Minimal Dimension K^{th}-Order Robust Servo-Regulator," Proceedings IEEE Conference on Decision and Control, 13 December 1996, Kobe, Japan.

CONFERENCE PRESENTATIONS:

Kang, W., "Bifurcations of Non Linear Control Systems and their Classification," UC 12th Annual Conference in nonlinear Science, Santa Cruz, CA, 24 February 1996.

Kang, W., "Bifurcation phenomena of systems with uncontrollable linearization," presentation at MTNS96, St. Louis, MO, 24 June 1996.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Surface/Under Surface Vehicles - Ships and Watercraft

KEYWORDS: Nonlinear H-infinity control, bifurcations, invariants, normal forms

CLOSE COMBAT ANTIARMOR WEAPON SYSTEM (CCAWS)

Bard K. Mansager, Senior Lecturer
Department of Mathematics
Sponsor: U.S. Army-Redstone Arsenal

OBJECTIVE: To provide the Program Manager (PM), CCAWS, information regarding the sensitivity of weapon parameters for three candidate systems using the measures of effectiveness of survivability and lethality.

SUMMARY: This research examined three technologies in both offensive and defensive scenarios using the TOW2B as a baseline for comparison. The three systems were modeled using the JANUS Combat Simulation. Weapon system variables included the system preparation time which measures the time that is needed between missile shots. Also included is modeling the ability of the system to fire on the move. Additionally, Shoot and Scoot tactics were modeled. Use of this tactic allows the antitank crew to move to an alternate location after firing. Variables within the model database include four values for System Prep Time (0, 10, 15, and 20 seconds), two Firing Modes (Firing on the Move or not), and four times before the system can "Shoot and Scoot" (0, 6, 15, and 20 seconds). Using a full factor design of experiment, a comparison of these variables using system Survivability and Engagement Range as measures of effectiveness was conducted. The final report will also include possible insights into the effectiveness of current tactics and if possible suggest modifications that will take advantage of the new technologies.

PUBLICATION:

Mansager, Bard K., "Close Combat Antiarmor Weapons Systems (CCAWS) Technology Analysis," NPS-MA-96-001, Naval Postgraduate School, Monterey, CA, January 1996.

THESIS DIRECTED:

Lovaszy, S.A., "Comparison of Bradley M2A2 and M2A3 Using JANUS," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Antitank missiles, close combat antitank systems, TOW missile improvements

GLOBAL POSITIONING SYSTEM (GPS) DATA INTERPOLATION

B. Neta, Professor
D.A. Danielson, Professor
Department of Mathematics
J.R. Clynch, Research Professor
Department of Oceanography
Sponsor: NISE-West Coast Division

OBJECTIVE: Discuss and compare several methods for polynomial interpolation of Global Positioning System ephemeris data.

SUMMARY: A technical report was prepared comparing the accuracy and speed of various interpolators for GPS satellite orbits. The results were presented in a meeting of the AAS/AIAA in San Diego, CA, July 29-31 1996.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Artificial satellites, parallel computers, orbit prediction

SATELLITE UMBRA/PENUMBRA ENTRY AND EXIT POSITIONS

B. Neta, Professor
Department of Mathematics
Sponsor: U.S. Air Force-Phillips Laboratory

OBJECTIVE: Conversion of the catalog used by NAVSPACECOM to a data set that the DSST code can use; technical editing of advanced astrodynamics textbook and computation of entry and exit positions of a satellite in and out of umbra and penumbra regions.

SUMMARY: The problem of computing Earth satellite entry and exit positions through the Earth's umbra and penumbra, for satellites in elliptical orbits, is solved without the use of a quartic equation. A condition for existence of a solution is given. This problem is related to perturbation force resulting from solar radiation pressure.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Satellites, orbit prediction, umbra/penumbra

THE IMPLEMENTATION OF A SEMI-LAGRANGIAN METHOD TO THE NAVAL RESEARCH LABORATORY'S GLOBAL OCEAN CIRCULATION MODEL

B. Neta, Professor
Department of Mathematics
Sponsor: Naval Research Laboratory

OBJECTIVE: The implementation of a semi-implicit semi-Lagrangian method to the NRL global ocean circulation model is proposed. The ocean model currently employs a combination of an Eulerian and semi-Lagrangian method which then limits the time step as indicated by the CFL stability condition. For this reason a fully semi-implicit semi-Lagrangian method will be implemented because this method is not restricted by the same stability condition that govern Eulerian algorithms. In addition, efficient iterative methods will be explored including preconditioned conjugate gradient and conjugate gradient squared methods.

SUMMARY: The analysis of the Turkel-Zwas scheme for solving the shallow water equations on the sphere are finished. The results show the need for certain staggering of the unknowns. The staggered scheme was developed and tested. A paper was submitted and the software developed for both the unstaggered and staggered grids is available as a technical report and on Professor B. Neta's home page. The results were presented at the Prague Mathematical Conference in Prague, Czech Republic, July 8-12 1996.

DoD KEY TECHNOLOGY AREAS: Computing and Software

KEYWORDS: Semi-Lagrangian, ocean circulation

TARGETING UNDERGROUND ORGANIZATIONS

G. Owen, Professor
Department of Mathematics
G. McCormick, Associate Professor
Command, Control and Communications Academic Group
Sponsors: Assistant Secretary of Defense and Naval Postgraduate School-Institute of Joint Warfare Analysis

OBJECTIVE: This project has two objectives: 1) develop a format framework for evaluating the dynamics of sub-state conflict; and 2) use this framework to examine the ways in which to improve our ability to target terrorist organizations.

SUMMARY: The focus of this research project reflects the changing nature of the international conflict environment, which is now being increasingly defined by the proliferation of locally driven, ethnic, communal, and political wars. The high likelihood that the United States will continue to be drawn into such conflicts requires that we improve the *analytical aids needed to evaluate, measure, and respond* to such engagements effectively. This research project is designed to help satisfy this need by providing a series of interlocking studies examining the foundation and dynamics of sub-state conflict and the ways in which such dynamics can and cannot be *controlled, contained, diffused, and deterred.* Each study will identify and isolate the key factors and relationships that explain different parts of the larger sub-state conflict problem. We will then examine the various control mechanisms available to the United States and other actors interested in shaping the outcome of such conflicts.

PUBLICATIONS:

McCormick, G., and Owen, G., "The Dynamics of Revolutionary Conflict," (submitted).

McCormick, G., and Owen, G., "Revolutionary Origins and Conditional Mobilization," European Journal of Political Economy 1996, Vol. 12.

McCormick, G., and Owen, G., "Violence, Factionalism, and State-Terrorist Negotiations," (submitted).

DoD KEY TECHNOLOGY AREAS: Other (Terrorism)

KEYWORDS: Substate conflict, terrorist

CONDITIONAL ANNIHILATION AND COMPLETION IN CLASSES OF CHORDAL GRAPHS

Craig W. Rasmussen, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The goals of this project are to discover the feasibility of exploiting a recently-revealed partial ordering relation on the chordal graphs to produce improved heuristics for solving a variety of NP-complete graph problems that arise in applications.

SUMMARY: This summary covers the continuation of a project that was initiated in FY94 and which was partially funded by the Naval Postgraduate School in FY95 and FY96. The work has its roots in work done in the 1980s by Grone, Johnson, et al., which showed that for any chordal graph there exists a sequence of edge insertions with the property that each of the resulting graphs is chordal. The existence of such a completion sequence provided the solution to a difficult problem in matrix theory. Subsequent work by this investigator has shown that a number of other classes of graphs allow such completion sequences, and that efficient algorithms can be devised for construction of such sequences; these algorithms exploit certain vertex labellings, called elimination orderings, that are associated with various subclasses of the chordal graphs. More recently this investigator has shown that the construction is reversible, in the sense that it is also possible to devise an annihilation sequence for a chordal graph, i.e., a sequence of edge deletions that preserves chordality. Like the algorithm for constructing completion sequences, an efficient algorithm for constructing an annihilation sequence for a chordal graph exploits a selected perfect elimination ordering. Analogous results have been obtained for a number of subclasses of the chordal graphs using elimination orderings specific to those subclasses.

As a consequence of these results, it is now apparent that the chordal graphs and many of their subclasses exhibit a surprisingly rich structure, with the chordal graphs of fixed order constituting a partial order containing as suborders the strongly chordal, interval, unit interval, split, and threshold graphs. The emphasis is now on development of applications; the most likely applications are heuristic methods for constructing near-solutions to a variety of NP-complete problems, including graph coloring and maximum clique.

PUBLICATIONS:

Carroll, T. and Rasmussen, C.W., "A Partial Ordering of the Chordal Graphs," NPS Technical Report to appear in 1997.

CONFERENCE PRESENTATIONS:

Rasmussen, C.W., "Annihilation Algorithms for Classes of Chordal Graphs," 27th Southeastern International Conference on Combinatorics, Graph Theory, and Computing, Baton Rouge, LA, February 1996.

Rasmussen, C.W., "A Partial Ordering of the Chordal Graphs by Edge Set Inclusion," Colloquium Presentation, Department of Mathematics, University of Louisville, Louisville, KY, April 1996.

THESES DIRECTED:

Carroll, T., "Edge Annihilation Sequences for Classes of Chordal Graphs," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Other (Applied Mathematics).

KEYWORDS: Chordal graph, NP-complete problems, annihilation sequence

P-COMPETITION GRAPHS: CHROMATIC PROPERTIES AND CHARACTERIZATIONS

Craig W. Rasmussen, Assistant Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: Characterize competition graphs and p-competition graphs of various highly structured families of graphs and digraphs.

SUMMARY: This is ongoing work that is conducted jointly with colleagues at Colorado University at Denver, Kenyon College, and the University of the Pacific. The project is an outgrowth of a project that was supported during FY93 and FY94 by the Naval Postgraduate School.

PUBLICATIONS:

Langley, L., Lundgren, J.R., McKenna, P.A., Merz, S.K. and Rasmussen, C.W., "p-Competition Graphs of Strongly Connected and Hamiltonian Digraphs," accepted for publication in Ars Combinatoria.

Lundgren, J.R., McKenna, P.A., Merz, S.K. and Rasmussen, C.W., "p-Competition Graphs of Symmetric Digraphs and Neighborhood Graphs," submitted, (Journal of Combinatorics, System and Information Sciences).

DoD KEY TECHNOLOGY AREAS: Other (Communications Networking, Resource Allocation.

KEYWORDS: P-Competition graphs

ASSESSMENT OF DAMAGE AGGREGATION FOR WEAPONS SALVOS

I.B. Russak, Professor
Toke Jayachandran, Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The following notation in all that follows: For a salvo of weapons launched at an area target, let D(k) be the proportion of the target that is damaged as a result of k weapon hits and E(D) the expected value of D(K) from the salvo. Esary studied the properties of an extant formula referred to as the empirical rule for approximating E(D). In his work Esary made certain assumptions that lead to a formula for D(k). The objectives of this work are two-fold as follows: (1) to improve the approximation of the empirical formula, and (2) to obtain results for D(k) and E(D) when a number of Esary's assumptions are removed. In particular the assumption of proportional damage aggregation (which avoids the determination of how damage actually aggregates) and the assumption of predetermined target cell locations with weapon hits effectively occurring in the center of a cell are addressed.

SUMMARY: For (1): the attractiveness of the empirical rule stems from the fact that only a knowledge of the mean of the weapons impact probability distribution is needed to use the formula. The proposed improvement is achieved by applying the Taylor Series approximation to the function representing the expected cumulative damage. The resulting modified formula which requires a knowledge of the variance in addition to the mean, provides a significant improvement in the accuracy of approximation when estimating the expected cumulative damage. For (2): the work consists of two parts as follows: a simulation package is being developed to determine numerically the aggregation of damage in cases where proportional damage seems unlikely and also to verify results otherwise obtained. Concerning the assumption of predetermined cell locations and its implications. The method of the present research, is to use a combination of predetermined cells together with a limiting technique in which the target is composed of more and more cells which grow smaller and smaller and to obtain a formula for D(k) from this limiting process. Since in this process, cells

effectively reduce to points, then a hit to a cell is a hit to a point thus avoiding the problems associated with predetermined cells.

PUBLICATIONS:

Jayachandran, T., and Russak, I.B., "Assessment of Damage Aggregation for Weapons Salvos," Naval Postgraduate School Technical Report, to appear in April 1997.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Conventional Weapons

KEYWORDS: Estimation weapons, salvos, damage assessment

AIRCRAFT ENGINE PERFORMANCE IMPROVEMENT

W.M. Woods, Professor
Department of Mathematics
Sponsor: Naval Air Systems Command

OBJECTIVE: To develop optimal no-build times relative to hard inspection times for critical components of fielded TF34 aircraft engines.

SUMMARY: Repair of a critical component in an aircraft engine can be performed for cost C1 when the engine is off the wing (now) under repair due to a failure that does not involve the critical component which has hard inspection time T and current accumulated test time, X. If not repaired now the critical component can be repaired at next engine failure if it occurs before total operating time T has accumulated on the critical component (again for cost C1) or cost C2 if total operating time accumulates to T before the next engine failure. If the critical component fails before the next engine failure due to other reasons, the repair cost of the critical component is C3. The no-build time, X0, is minimum value of accumulated time, X, on the critical component for which repair on the critical component should occur when the engine is off the wing due to failure for reasons other than the critical component. The optimal no-build time, X0, is the value of X0 which makes the expected repair cost per operating hour when repair is down (now) equal to the expected repair cost per hour when the decision is made to wait for the next failure. Expected repair cost per operating hour is computed assuming Weibull failure time probability distributions for the engine and the critical component using TF34 engine failure data from the NALDA data base. An integral equation was developed that can be solved to determine the optimal no-build time X0. X0 depends on the parameters of the two Weibull distributions and the two ratios C2/C1 and C3/C1. Graphs are provided that show how X0 changes as these two ratios change.

DoD KEY TECHNOLOGY AREAS: Other (System Effectiveness)

KEYWORDS: Optimal maintenance, system effectiveness

SHIP MISSILE DEFENSE EFFECTIVENESS

W.M. Woods, Professor
Department of Mathematics
Sponsor: Naval Warfare Assessment Center

OBJECTIVE: To develop a probabilistic system effectiveness equation that can be used to compute the probability that an Exocet missile will not hit a DD-963 Spruance Class Destroyer given ship configuration, weapons firing policy, weapons systems availabilities, and weapons system conditional kill probabilities given crew readiness state and Exocet detection range.

SUMMARY: The probability that a DD-963 Spruance Class Destroyer can kill an incoming Exocet missile depends on the capabilities of 22 subsystems including the NATO Seasparrow Missile System, the MK45 guns, the Chaff, the

CWIS, and the MK23 TAS Radar. It also depends on the crew readiness state, the range of the Exocet when detected, the firing policy of these systems, and the availability of the critical subsystems; e.g., TAS. An equation for computing this kill probability was developed and an Excel spreadsheet developed for performing the computations given the parameter values in the equation.

THESIS DIRECTED:
Johns, Richard O., "AAW Effectiveness of the DD-963 Spruance Class Destroyer: An Analytic Approach," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Other (System Effectiveness)

KEYWORDS: Missile defense effectiveness, system effectiveness

PUBLICATIONS/PRESENTATIONS

JOURNAL PAPERS

Barr, D.R. and Mansager, B., "Terrain Map Resolution," International Journal of Mathematical and Computer Modeling, Vol. 23, pp. 39-46 1996.

Briggs, W.L. and Henson, V.E., "A Table of Analytical Discrete Fourier Transforms," Applied Numerical Mathematics, Vol. 20, pp. 1-10.

Cersovsky, D., Kleinschmidt, E., Neta, B., and Mansager, B., "Audio Detection Algorithms in Combat Simulations," International Journal of Mathematical and Computer Modeling, Vol. 23, pp. 65-72 1996.

Fahroo, F., and Ito, K., "Optimum Damping Design For An Abstract Wave Equation," Kybernetika, Vol. 32, No. 6, pp. 557-574 1996.

Fortanbary, M.W., Mansager, B.K., and Newberry, C.F., "Supporting Acquisition Decisions Through Effective Experimental Design," International Journal of Mathematical and Computer Modeling, Vol. 23, pp. 81-90 1996.

Frenzen, C.L. and Frame, J.S., "Approximating e^n/2 With Nearly n+1/3 Terms," Pi Mu Epsilon Journal, Vol. 10, No. 5, Fall 1996.

Henson, V.E., Limber, M.A., McCormick, S.F., and Robinson, B.T., "Multilevel Image Reconstruction with Natural Pixels," SIAM Journal Of Scientific Computing, Vol. 17, No. 1, pp. 193-216 1996.

Kang, W., "Extended Controller Form and Invariants of Nonlinear Control Systems with a Single Input," Journal of Mathematical System, Estimation and Control, 6, pp. 27-51 1996.

McCormick, G., and Owen, G., "Revolutionary Origins and Conditional Mobilization," European Journal of Political Economy, Vol. 12 1996.

Neta, B. and Knorr, J.B., "Running NEC4 on the Cray at Navak Postgraduate School," Applied Computational Electromagnetic Society Newsletter, Vol. 11, No. 3, pp. 12-15 1996.

CONFERENCE PAPERS

Canright, D. and Henson, "A FVE-FAC Approach to Determining Thermocapillary Effects on Weld Pool Shape," Refereed by conference organizers, in Proceedings of the 7th Copper Mountain Conference on Multigrid Methods, NASA Conference Publication 3339, pp. 147-166 1996.

Danielson, D.A. et al., "Fast Interpolation for Global Positioning System Satellite Orbits," Proceedings AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, paper number 96-3658, 29-31 July 1996.

Delgado, H.J. and Fausett, L.V., "Parallel Solution of a Linear System Using an SOR Neural Network," Proceedings of Southcon96, Orlando, FL, 25-27 June 1996.

Elwasif, W.R., and Fausett, L.V., "Function Approximation Using a Sinc Neural Network," Applications and Science of Artificial Neural Networks II, S. K. Rogers and D. W. Ruck (eds.), SPIE, Volume 2760, pp. 690-701 1996.

Fahroo, F., "Exponential Stability of Polynomial Galerkin Methods for an Acoustic-Structure Model," Procedings of the 4th IEEE Mediterranean Symposium on New Directions in Control and Automation, Crete, Greece, June 1996.

PUBLICATIONS/PRESENTATIONS

Fausett, L.V., "Similarity Based Learning for Pattern Classification," Applications and Science of Artificial Neural Networks II, S.K. Rogers and D.W. Ruch (eds.), SPIE, Volume 2760, pp. 26-33 1996.

Kang, W., "Bifurcation and Topology of Equilibrium Sets," Proceedings IEEE Conference on Decision and Control, December 1996.

Kang, W. and Huang, J., "Calculation of the Minimal Dimension K^{th}-Order Robust Servo-Regulator," Proceedings IEEE Conference on Decision and Control,Kobe, Japan, December 1996.

Lee, J., Beach, C.D., and Fausett, L.V., "Channel Equalization Via Fuzzy ARTMAP," Proceedings of the 7th International Conference on Signal Processing Applications & Technology, Vol. 2, pp.1397-1401, Miller Freeman, Inc. 1996.

Neta, B., Sagovac, C.P., Danielson, D.A., and Clynch, J.R., "Fast Interpolation for Global Positioning System (GPS) Satellite Orbits," Proceedings AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, Paper Number 96-3658, 29-31 July 1996.

Park, C.-Y. and Fausett, D.W., "Determination of Adaptively Adjusted Coefficients for Hopfield Neural Networks Utilizing the Energy Function," Applications and Science of Artificial Neural Networks II, S. K. Rogers and D. W. Ruck (eds.), SPIE, Vol 2760, pp. 36-43 1996.

Russell, G. and Fausett, L.V. "Comparison of Function Approximation with Sigmoid and Radial Basis Function Networks," Applications and Science of Artificial Neural Networks II, S. K. Rogers and D. W. Ruck (eds.), SPIE, Volume 2760, pp. 61-72 1996.

CONFERENCE PRESENTATIONS

Delgado, H.J. and Fausett, L.V., "Parallel Solution of a Linear System Using an SOR Neural Network," Southcon96, Orlando, FL., 25-27 June 1996.

Elwasif, W.R. and Fausett, L.V., "Function Approximation Using a Sinc Neural Network," Applications and Science of Artificial Neural Networks, SPIE, Orlando, Florida, 9-12 April 1996.

Fahroo, F., and Ito, K., "Variational Formulation of Optimal Damping Designs," AMS conference on Control of Distributed Parameter Systems, at Mount Holyoke College, MA, June 1996.

Fahroo, F., "A New Model of Acoustic-Structure Interaction and its Exponential Stability," MTNS 96 Conference, St. Louis, MO, 24-28 June 1996.

Fahroo, F., "Exponential Stability of Galerkin Methods for an Acoustic-Structure Model," SIAM Annual Conference, Kansas City, KS, July 1996.

Fahroo, F., "Numerical Experiments on Approximated Acoustic-Structure Systems," Conference on Computation and Control, Bozeman, MT, August 1996.

Fausett, L.V., "Similarity Based Learning for Pattern Classification," Applications and Science of Artificial Neural Networks, SPIE, Orlando, FL, 9-12 April 1996.

Henson, V.E., "Image Reconstruction from Projections using Adjoint Interpolation," Copper Mountain Conference on Iterative Methods, April 1996.

PUBLICATIONS/PRESENTATIONS

Kang, W., "Bifurcations of Nonlinear Control Systems and their Classification," UC 12th Annual Conference in nonlinear Science, Santa Cruz, CA, February 24 1996.

Kang, W., "Bifurcation Phenomena of Systems with Uncontrollable Linearization," MTNS96, St. Louis, MO, 24 June 1996.

Kang, W., "Bifurcation and Topology of Equilibrium Sets," IEEE Conference on Decision and Control, Kobe, Japan, 12 December 1996.

Neta, B., Giraldo, F.X., and Navon, I.M., "Analysis of the Turkel-Zwas Scheme for the Two-Dimensional Shallow Water Equations in Spherical Coordinates," presented at 1996 Prague Mathematical Conference, Prague, Czech Republic, 8-12 July 1996.

Park, C.-Y. and Fausett, D.W., "Determination of Adaptively Adjusted Coefficients for Hopfield Neural Networks Utilizing the Energy Function," SPIE 10th Annual International AeroSense Symposium, Orlando, FL, 8-12 April 1996.

Park, C.-Y., and Fausett, D.W., "Energy Function Analysis for Improved Performance of Hopfield-Type Neural Networks," ANNIE '95 Artificial Neural Networks in Engineering Conference, St. Louis, MO, 12-15 November 1995.

Rasmussen, C.W., "Annihilation Algorithms for Classes of Chordal Graphs," 27th Southeastern International Conference on Combinatorics, Graph Theory, and Computing, Baton Rouge, LA, February 1996.

Rasmussen, C.W., "A Partial Ordering of the Chordal Graphs by Edge Set Inclusion," Colloquium Presentation, Department of Mathematics, University of Louisville, Louisville, KY, April 1996.

Russell, G. and Fausett, L. V., "Comparison of Function Approximation with Sigmoid and Radial Basis Function Networks," Applications and Science of Artificial Neural Networks, SPIE, Orlando, FL, 9-12 April 1996.

Weber, Timothy, Mansager, B.K., and Borges C., "Modeling a Swarming Approach to Mine Countermeasures in an Amphibious Assault," 64th Military Operations Research Society Symposium, Ft. Leavenworth, KS, June 1996.

TECHNICAL REPORTS

Danielson, D., "Buckling of Ship Grillages," Naval Postgraduate School Technical Report NPS-MA-96-002, September 1996.

Jayachandran, T., "Correlation in Multiversion Software," Naval Postgraduate School Technical Report NPS-MA-96-003, October 1996.

Mansager, B.K., "Close Combat Antiarmor Weapons Systems (CCAWS) Technology Analysis," NPS-MA-96-001, Naval Postgraduate School, January 1996.

Neta, B., and Vallado, D., "On Satellite Umbra/Penumbra Entry and Exit Positions," NPS-MA-96-005, Technical Report 1996.

Weber, T., Mansager, B., and Borges, C.F., "High Resolution Modeling of Naval Mine Countermeasures," Technical Report NPS-MA-96-004, September 1996.

MATHEMATICAL MODELING USING MAPLE

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The area of higher mathematics begins with successive courses in calculus; however, rarely does the calculus student recognize the applications or impetus for the mathematical skills that are taught. Giordano and Weir produced A *First Course in Mathematical Modeling,* the first text which addressed this shortcoming in the curriculum of every science and engineer field. With the advent of powerful classroom computers, Fox, Maddox, Giordano and Weir produced *Mathematical Modeling With Minitab,* which assists the student in translating the theory into a computer language. At the Naval Postgraduate School, Maple is the software used most commonly in the Mathematics Department, requiring a similar instructing tool. Mathematical Modeling using Maple follows the lead of *Mathematical Modeling With Minitab,* and assists the student in grasping the concepts of the modeling class without getting slowed down by the syntax of Maple.

IMPLEMENTATION AND EFFICIENCY OF STEGANOGRAPHIC TECHNIQUES IN BITMAPPED IMAGES AND EMBEDDED DATA SURVIVABILITY AGAINST LOSSY COMPRESSION SCHEMES

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The term steganography is descriptive of techniques used to covertly communicate by embedding a secret message within an overt message. Such techniques can be used to hide data within digital images with little or no visible change in the perceived appearance of the image and can be exploited to covertly export sensitive information. This thesis explores the data capacity of bitmapped image files and the feasibility of devising a coding technique which can protect embedded data from the deleterious effects of lossy compression.

In its simplest form, steganography in images is accomplished by replacing the least significant bits of the pixel bytes with the data to be embedded. Since images are frequently compressed for storage or transmission, it is desirable that a steganographic technique include some form of redundancy coding to counter the errors caused by lossy compression algorithms. Specifically, the Joint Photographic Expert Group (JPEG) compression algorithm, while producing only a small amount of visual distortion, introduces a relatively large number of errors in the bitmap data. These errors will effectively garble any non-coded steganographically embedded data.

This thesis shows that, although there are numerous protocols for embedding data within pixels, the limiting factor is always the number of bits modified in each pixel. A balance must be found between the amount of data embedded and the amount of acceptable distortion. This thesis also demonstrates that, despite errors caused by compression, information can be encoded into pixel data so that it is recoverable after JPEG processing, though not with perfect accuracy.

EDGE ANNIHILATION SEQUENCES FOR CLASSES OF CHORDAL GRAPHS

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Given a non-empty graph $G= (V,E)$ of order n and size m, with some property P, we may ask whether there exists a sequence of graphs constructed by the sequential removal of edges $e_1, e_2, ..., e_m$, with the property that if $G_0 = G$ then (1) G_i obtained from G_{i-1} by deletion of exactly one edge and (2) G has property P for $1 \leq i \leq m$. We refer to such a sequence as an edge annihilation sequence. If G is chordal, strongly chordal, split, threshold, interval or unit interval, then we show that there exists an edge annihilation sequence for G. Algorithms and necessary vertex orderings are given for the construction of edge annihilation sequences for the above mentioned classes of graphs. We know that for $G^{(n)}$, the set of all labeled graphs $G = (V,E)$ of order n, $(G, \leq)$ is a partially ordered set (poset) under edge set inclusion. Using edge annihilation sequences and edge completions sequences, we discuss the construction of a chain of graphs in $G^{(n)}$ with property P. We show that within $G^{(n)}$, every graph with property P lies on at least one chain of graphs with property P.

A MATHEMATICAL MODEL ANALYSIS OF MINE COUNTERMEASURES IN A HARBOR CHANNEL

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Mines are extremely effective weapons, they are small, cheap, easy to hide, easy to store, and can be clandestinely laid from virtually any type of platform. They have become the favorite weapon of informal forces, such as terrorists, because they are also very easy to obtain (Eastern Bloc stores, etc.).

This thesis is based on the idea of utilizing the significant threat of the mine to interrupt the sea transportation of a specific harbor by laying mines in the harbor channels. The host country will clear all the mines as soon as possible to insure smooth transportation. By using the Janus war-gaming simulation, three scenarios were created to compare various Mine Counter Measures (MCM) approaches. Each scenario has the same red force (the mines laid in the harbor) against two types of blue forces. The first scenario gives a baseline for what would be expected should no mine clearing take place. The second one is the current Naval MCM forces, which are mine-sweepers and mine-hunters, of a certain Asian country. The last one applies a new technology, Lemmings, in the MCM force.

A comparative analysis of these three scenarios will be performed, examining the measures of effectiveness of merchant ships killed, time consumption of mine-clearing, and percentage of mines neutralized.

COMBAT SIMULATION MODELING IN NAVAL SPECIAL WARFARE MISSION PLANNING

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This thesis explores the potential role of combat simulation modeling in the Naval Special Warfare mission planning cycle. It discusses methods for bridging the gap between the simulation and mission planning processes, addressing strengths and weaknesses as well as employment considerations.

This thesis describes the processes involved in modeling and simulation and discusses how the stochastic nature of simulation is particularly relevant to combat. Deliberate, Time-sensitive, and Dynamic mission planning are described and the commonality of tactical planning in each instance is established. Based on this framework, a notional SEAL scenario is used to illustrate the role of simulation in each type of mission planning, focusing primarily on the tactical

level. The thesis concludes by discussing additional applications of combat simulation modeling within the Naval Special Warfare community and makes recommendations for its effective and efficient implementation.

THE USE OF HÉNON BINARY SEQUENCES FOR DIRECT SEQUENCE SPREAD SPECTRUM CODE GENERATION

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In this thesis, the generation of secure codes using chaotic pseudo-random sequences and a generalized Geffe generator is investigated. These codes are tested for cryptographic security and applicability for use in a spread spectrum communications system. It is shown that the codes appear to be cryptographically sound and suitable for use in a multi-user environment, but do not significantly enhance the security of the spread spectrum system. Further simulation of the spread spectrum system is utilized to investigate the effect of errors in receiver spreading codes.

MATHEMATICAL MODELING AND ANALYSIS OF SURVIVABILITY AND MORBIDITY RATES

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The goal of this thesis is to show the feasibility of using Janus(A), a high resolution combat simulator, as a planning and training tool for analyzing, with graphical methods, when and where casualties will occur on the battlefield. These results can be used for estimating the type and number of casualties, and planning evacuation routes, casualty collection points and necessary medical resources.

In order to show the utility of this approach, this thesis presents results from three different scenarios. This will allow the analyst to see how the visualization exhibits the different outcomes. All three scenarios are run with data from the Marine Corps' Operation Kernel Blitz-95, the largest combat medical exercise since the Korean War. Scenario one will be conducted with the amphibious landing force 'bulling ahead' with little to no offshore minefield breaching operations being conducted prior to the assault. Scenario two will utilize a more traditional method of offshore breaching. Scenario three will then use the Autonomous Legged Underwater Vehicle (ALUV) to breach the surf zone mine fields prior to the landing.

A COMBAT SIMULATION ANALYSIS OF AUTONOMOUS LEGGED UNDERWATER VEHICLES

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Autonomous Legged Underwater Vehicles (ALUVs) are inexpensive crab-like robotic prototypes which will systematically hunt and neutralize mines en masse in the very shallow water and the surf zone (VSW/SZ). With the advent of mine proliferation and the focal shift of military power to the littorals of the world, ALUVs have the potential to fill a critical need of the United States Navy and Marine Corps' mine countermeasure (MCM) forces.

Duplicating the MCM portion of the Kernel Blitz 95 exercise whenever feasible, this thesis uses the Janus interactive combat wargaming simulation to model and evaluate the effectiveness of the ALUV as a MCM. Three scenarios were developed: an amphibious landing through a minefield using no clearing/breaching; an amphibious landing through a minefield using current clearing/breaching techniques; and an amphibious landing through a minefield using ALUVs as the clearing/breaching method.

This thesis compares the three scenarios using landing force kills, cost analysis, combat power ashore, and percentage of mines neutralized as measures of effectiveness.

A TYPE INFERENCE ALGORITHM AND TRANSITION SEMANTICS FOR POLYMORPHIC C

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In an attempt to bring the ML-style type inference to the C programming language, Smith and Volpano developed a type system for a dialect of C, called PolyC [SmV96a] [SmV95b]. PolyC extends C with ML-style polymorphism and a limited form of higher-order function.

Smith and Volpano proved a type soundness theorem that basically says that evaluation of a well-typed PolyC program cannot fail due to a type mismatch. The type soundness proof is based on an operational characterization of a special kind of semantic formulation called a natural semantics. This thesis presents an alternative semantic formulation, called a transition semantics, that could be used in place of the natural semantics to prove type soundness. The primary advantage of the transition semantics is that it eliminates the extra operational level, but the disadvantage is that it consists of many more evaluation rules than the natural semantics. Thus it is unclear whether it is a suitable alternative to the two-level approach of Smith and Volpano.

Further, the thesis gives the first full type inference algorithm for the type system of PolyC. Despite implicit variable dereferencing found in PolyC, the algorithm turns out to be a rather straightforward extension of Damas and Milner's algorithm *W* for functional languages [DaM82]. The algorithm has been implemented as an attribute grammar in Grammatech's SSL and a complete source code listing is given in the Appendix.

MATRIX ALGEBRA

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The purpose of this thesis is to develop a textbook which presents basic concepts of matrix algebra from a primarily computational perspective, for an introductory course in matrix algebra at the Naval Postgraduate School (NPS). The need for an introductory matrix algebra text is generated by the unique characteristics of the student body at NPS. Students at NPS are beginning graduate studies after several years away from the academic environment. As a result, most students benefit from a course which presents fundamental concepts and techniques in solving matrix algebra problems which are needed for advanced studies in mathematics, engineering, and operations research. Current publications in matrix algebra go into more detail on linear algebra than is needed for the introductory course and many texts do not cover complex numbers in sufficient detail to meet the needs of the students. This text presents techniques for solving systems of linear equations, the algebra of matrices, the connection between linear systems and algebraic operations on matrices, and an introduction to eigenvalues, eigenvectors, and complex numbers. The intent is to hone student skills in applying fundamental techniques in matrix algebra essential to success in future courses.

QUANTITATIVE EVALUATION OF THE LIMITATIONS OF THE RADIATION BOUNDARY ELEMENTS IN THE FINITE ELEMENT CODE ATILA

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A quantitative evaluation of the limitations of the radiation boundary elements in the finite element code ATILA [Ref. 1] has been performed. Five three-dimensional models were employed, each representing a rigid spherical solid surrounded by water. Monopolar, dipolar and quadrupolar incident spherical waves were introduced and the corresponding scattered waves were computed using the ATILA code and an exact analytical solution.

The dimensionless parameters that characterize the problem are ka, kL, and kR where k is the wavenumber of sound in water, a is the radius of the scatterer, R is the outer fluid mesh radius, and L is the thickness of the fluid layer. The range of values investigated were kR=1.5, 2.5, 4.0, ka=0.5, 1.0, 2.0 and kL=0.5, 1.0.

For axially symmetric incident fields, the maximum normalized errors occurred at the poles and were 9%, 12%, and 6%, respectively. Furthermore, the errors for monopolar and dipolar incident fields were strongly influenced by the location of the radiation boundary (kR), less so by the scatterer's radius (ka); specifically, the error decreases with increasing kR and/or ka. The errors for quadrupolar incident fields do not exhibit any significant dependence on kR or ka. The errors for all the axially symmetric incident fields were not affected by variations of the element's size (kL). For non-axially symmetric incident fields, the maximum deviation occurred at the equatorial points and was less than 5.5%.

Further investigation using a two-dimensional model is proposed in order to determine the range of values of ka, kL, and kR which will result in negligibly small errors.

AN ANALYSIS OF LEMMINGS: A SWARMING APPROACH TO MINE COUNTERMEASURES IN THE VSW/SZ/BZ

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Lemmings are autonomous tracked underwater vehicles which utilize a swarming approach to mine detection and neutralization in the very shallow water, surf, and beach zones (VSW/SZ/BZ). The Navy and the Marine Corps are in great need of developing an effective "in stride" clearance/breaching method to further enhance the effectiveness and viability of their littoral warfare skills. The Lemmings system has the potential to fulfill this critical need in a cost effective, reliable manner.

Utilizing the Janus interactive wargaming simulation, an amphibious operation was modeled, with the amphibious landing taking place through a minefield in the littoral zones. Three scenarios of this model were developed: an amphibious landing through a minefield utilizing no clearing/breaching assets; an amphibious landing through a minefield utilizing current clearing/breaching assets, and an amphibious landing through a minefield utilizing Lemming swarms as the clearing/breaching assets.

A comparative analysis of these three scenarios will be performed, examining the measures of effectiveness of landing vehicles killed/damaged, combat power ashore at a given time, MCM assets killed, and percentage of mines neutralized.

A COMPUTER SIMULATION ANALYSIS OF ALTERNATIVES TO THE M728 COMBAT ENGINEER VEHICLE (CEV)

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This thesis compares the speed of breaching obstacles and the effects on survivability of the force provided by the Combat Engineer Vehicle (CEV) and two proposed replacement alternatives, the M1-CEV and the M1 with Blade, using the Janus (A) combat simulation. By doctrine, engineer units support the maneuver commander by providing the equipment and expertise for breaching operations. The CEV is a critical breaching asset that has reached the end of its operational lifetime. Most units have been ordered to turn in their CEVs by the end of fiscal year 1996. The proposed replacement, the M1 Breacher, is not to be fielded until the year 2000. Also, the M1 Breacher will not be able to perform all of the tasks that the CEV performs. As a result, the Army is seeking an alternative to the CEV to fill the void left by turning them in before the fielding of the M1 Breacher. This thesis examines the effects these three vehicles have on survivability and speed of breaching in a deliberate breaching scenario. Data related to survivability and speed are generated by the Janus simulation runs and analyzed using graphical and statistical methods.

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